

Holzmann, Robert; Alonso-García, Jennifer; Labit-Hardy, Heloise; Villegas, Andres M.

Working Paper

NDC Schemes and Heterogeneity in Longevity: Proposals for Redesign

IZA Discussion Papers, No. 11193

Provided in Cooperation with:

IZA – Institute of Labor Economics

Suggested Citation: Holzmann, Robert; Alonso-García, Jennifer; Labit-Hardy, Heloise; Villegas, Andres M. (2017) : NDC Schemes and Heterogeneity in Longevity: Proposals for Redesign, IZA Discussion Papers, No. 11193, Institute of Labor Economics (IZA), Bonn

This Version is available at:

<https://hdl.handle.net/10419/176997>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

DISCUSSION PAPER SERIES

IZA DP No. 11193

**NDC Schemes and Heterogeneity in
Longevity: Proposals for Redesign**

Robert Holzmann
Jennifer Alonso-García
Heloise Labit-Hardy
Andrés M. Villegas

DECEMBER 2017

DISCUSSION PAPER SERIES

IZA DP No. 11193

NDC Schemes and Heterogeneity in Longevity: Proposals for Redesign

Robert Holzmann

*Austrian Academy of Sciences; CEPAR, UNSW;
RCSS, University of Malaya; IZA and CESifo*

Jennifer Alonso-García

CEPAR, UNSW

Heloise Labit-Hardy

CEPAR, UNSW

Andrés M. Villegas

UNSW and CEPAR

DECEMBER 2017

Any opinions expressed in this paper are those of the author(s) and not those of IZA. Research published in this series may include views on policy, but IZA takes no institutional policy positions. The IZA research network is committed to the IZA Guiding Principles of Research Integrity.

The IZA Institute of Labor Economics is an independent economic research institute that conducts research in labor economics and offers evidence-based policy advice on labor market issues. Supported by the Deutsche Post Foundation, IZA runs the world's largest network of economists, whose research aims to provide answers to the global labor market challenges of our time. Our key objective is to build bridges between academic research, policymakers and society.

IZA Discussion Papers often represent preliminary work and are circulated to encourage discussion. Citation of such a paper should account for its provisional character. A revised version may be available directly from the author.

ABSTRACT

NDC Schemes and Heterogeneity in Longevity: Proposals for Redesign¹

Strong and rising empirical evidence across countries finds that longevity is highly heterogeneous in key socioeconomic characteristics, including income. A positive relationship between lifetime income and life expectancy at retirement amounts to a straight tax/subsidy mechanism when the average cohort life expectancy is applied for annuity calculation, as done under nonfinancial defined contribution (NDC) schemes. Such a regressive redistribution and the ensuing labor market distortion put into doubt main features of the NDC scheme and call for alternative benefit designs to compensate for the heterogeneity. This paper explores five key mechanisms of compensation: individualized annuities; individualized contribution rates/account allocations; a two-tier contribution structure with socialized and individual rate structure; and two supplementary approaches under the two-tier approach to deal with the income distribution tails, and the distortions above a ceiling and below a floor. Using unique data from England and Wales and the United States, the analysis indicates that both individualized annuities and a two-tier contribution scheme are feasible and effective and thus promising policy options. To this end, however, a de-pooling of gender will be required.

JEL Classification: D9, G22, H55, J13, J14, J16

Keywords: tax/subsidy structure, proxied life expectancy,
two-tier contribution structure, gender de-pooling

Corresponding author:

Robert Holzmann
Austrian Academy of Sciences
Dr. Ignaz Seipel-Platz 2
1010 Vienna
Austria
E-mail: robert.holzmann@oeaw.ac.at

¹ Revised paper prepared for the 3rd NDC Conference, Rome, October 5 & 6, 2017, Session/theme 3 on (F&N)DC Schemes and Longevity. The revision profited from comments by conference participants, discussions with colleagues at CEPAR, and excellent copy-editing by Amy Gautam. The authors are responsible for any errors. The authors acknowledge funding from the ARC Center of Excellence in Population Ageing Research (grant CE110001029).

1 Introduction

Strong and rising empirical evidence shows that longevity is highly heterogeneous in key socioeconomic characteristics, including income status. Ayuso, Bravo, and Holzmann (2017a) review the literature on the main socioeconomic dimensions of heterogeneity in longevity, their past development, and likely future trends. This international evidence, currently available only for advanced economies, suggests that heterogeneity in longevity arises across many socioeconomic dimensions, is often sizable, is becoming more prevalent, and shows few signals of abating in the near future.

The scope and trend of such heterogeneity in longevity regarding measures of lifetime income create a major concern for providers of lifetime annuities – namely, private insurance companies under voluntary and mandated funded defined contribution (FDC) schemes, and the rising number of countries that did or plan to adopt a nonfinancial defined contribution (NDC) scheme. Under an NDC approach, the initial pension benefit (lifetime annuity) is calculated at retirement by broadly dividing the notional account accumulations by the remaining (average) cohort life expectancy (see Holzmann 2017 for a primer on NDCs). When heterogeneity exists in the remaining life expectancy, some individuals profit at the expense of others in the social insurance pool. If life expectancy is positively correlated with lifetime income and with the level of accumulation, it is the lower-income groups that lose and the higher-income groups that profit from a common risk pool and application of a common life expectancy measure.

From a policy design perspective, heterogeneity in longevity with regard to income and contribution effort breaks the tight contribution – benefit link considered the signature feature of an NDC scheme: What you paid in you get out – not less and not more. Breaking the link creates new tax wedges that the reform from nonfinancial defined benefit (NDB) to NDC schemes aimed to eliminate. Such heterogeneity wedges also exist in NDB schemes beyond those created by explicit or implicit redistribution mechanism, but, given the benefit formula in NDB schemes, they are less visible. In an NDC scheme, one can more easily calculate the tax/subsidy wedge created by the heterogeneity in life expectancy at retirement, which has implications for individuals' decisions regarding formality, formal labor supply, and retirement age. Hence, left unaddressed, the risks associated with heterogeneity in life expectancy are threefold as it: invalidates or at least reduces the rationale for an NDC reform; renders an increase in retirement age as the key approach to deal with population aging less powerful and highly regressive; and creates an adverse redistribution, an outcome the NDC approach seeks to eliminate.

The objective of this paper is to explore in depth key policy options to address heterogeneity in longevity in NDC schemes. Some options were outlined by Ayuso, Bravo, and Holzmann (2017b); this paper deepens the analytical and empirical framework. To this end, Section 2 investigates the scope of the heterogeneity issue by using much more fine-grained data for the United States (US) and England and Wales (E&W) and estimating the distributions, not just point estimates, of the tax/subsidy mechanism. Section 3 presents alternative NDC designs to

address heterogeneity within a common analytical framework. Section 4 applies this analytical framework to the disaggregated data of Section 2 to gain a better understanding of feasibility, additional data needs, and empirical indications. Section 5 summarizes and outlines suggested next research steps.

2 Scope of the Issue and Policy Implications

While data on heterogeneity in longevity by various socioeconomic dimensions are increasingly available in advanced economies, the disaggregated link between life expectancy and measures of lifetime income remains the exception. Where data do exist, they are typically not suitable for examining this link. However, such disaggregated estimates across the whole income strata are critical to guide policy design options. The first part of this section presents estimated disaggregated information on the scope and distribution of heterogeneity based on data from the US and E&W. The second part uses this information to estimate the disaggregated tax/subsidy effects of heterogeneity for these two countries with regard to their measure of lifetime income. Section 2 ends with a brief discussion on the policy implications of these estimates.

2.1 Scope and Distribution of Heterogeneity in Life Expectancy

Individual lifetime incomes and the corresponding mortality data for a whole country are complex to establish and thus rarely available. Indeed, it requires combining various sources of data (such as tax declarations and death certificates). However, to gauge the relationship between (lifetime) income and life expectancy, we obtained related information for the US and E&W, as follows.

United States

Chetty et al. (2016) use federal income tax and social security records to investigate the relationship between (lifetime) income and life expectancy in the US. We use their data² to estimate life expectancy at age 65 by income percentile. The available data comprise mortality rates and populations counts for the US by sex and income percentile for ages 40–76 and calendar years 2001–2014. In this dataset, income is approximated by yearly pre-tax (individualized) household earnings adjusted to 2012 dollars using the consumer price index. Full details of the data collection and sources can be seen in Chetty et al. (2016).³

To estimate period life expectancy at age 65 by income percentile, we constructed sex-specific life tables by income percentile using a Gompertz-type generalized additive model linking log mortality rates to age, income percentile, and calendar year.⁴ Figures 1a and 1b illustrate the estimated relationship between income and period life expectancy at age 65. Here, nominal

² Available at <https://healthinequality.org/data/>; in particular, we use the data from online Table 15.

³ An alternative US dataset for exploration is that developed by the National Academies of Sciences, Engineering, and Medicine (2015). However, this dataset is not publicly available.

⁴ Mortality rates beyond age 76 were extrapolated using a variant of the method of Coale and Kisker (1990) under the assumption that mortality rates at ages 110 are equal to 0.7.

lifetime income values correspond to the sum of an individual's yearly pre-tax household earnings between age 20 and age 64, with earnings from age 20 to age 40 assumed to be equal to earnings at age 40.

Figure 1a: US period life expectancy in 2014 at age 65 by household income percentile

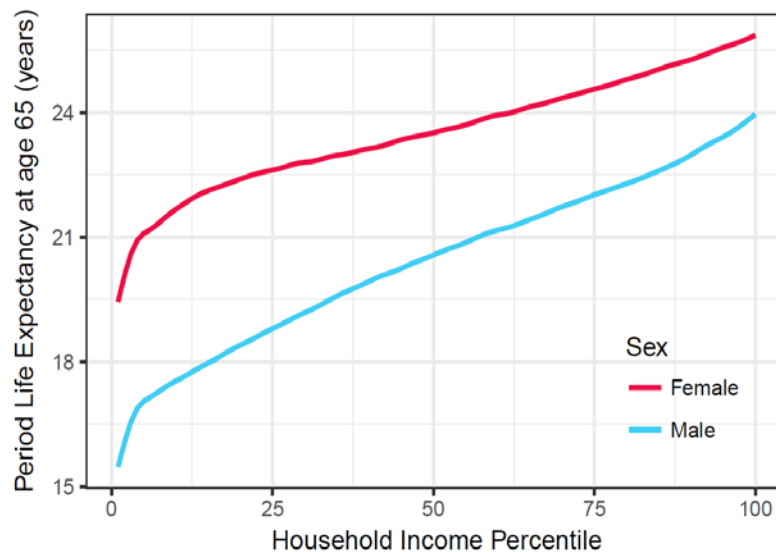
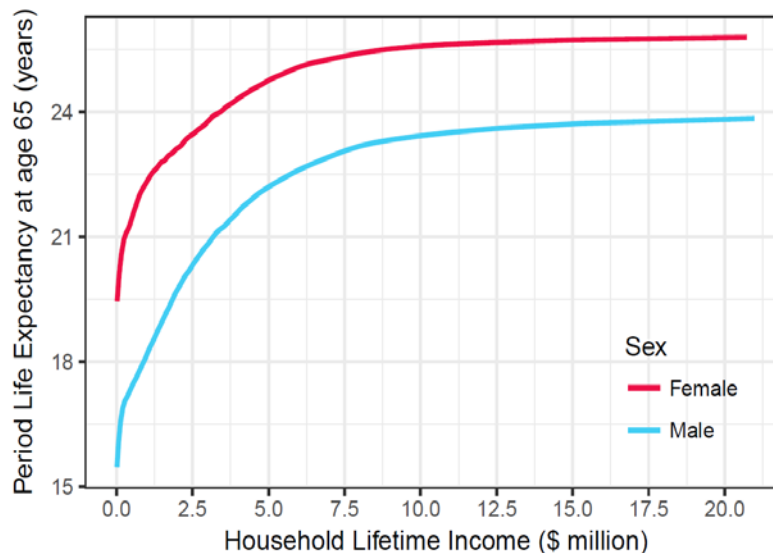


Figure 1b: US period life expectancy in 2014 at age 65 by nominal household income¹



Note: ¹The top income percentile is omitted for scaling purposes.

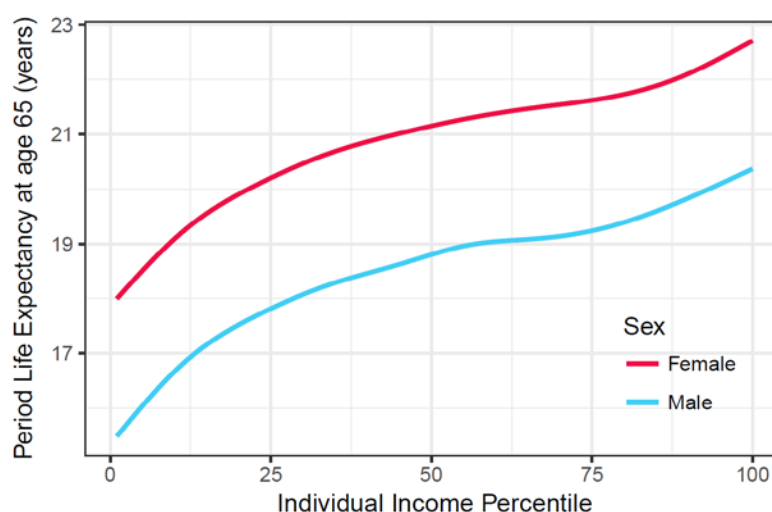
Source: Chetty et al. 2016, and own calculation.

Figure 1a indicates that in a percentile view of the income distribution, the link to life expectancy is broadly linear except in the lowest percentiles, and less pronounced in the highest percentiles. If mapped to the (real) income measure in dollars, the relationship to life expectancy is strictly concave, with the strongest curvature where most household incomes are situated.

England and Wales

E&W has no dataset linking a measure of individual lifetime income to life expectancy. Instead, we use area-level measures to approximate this relationship. In particular, we obtained income and mortality data for middle layer super output areas (MSOA) in E&W, which are statistical geographies used by the Office of National Statistics (ONS). The available data comprise ONS estimates of the total (gross) weekly household income at the MSOA level for the financial year ending 2014⁵, and number of deaths⁶ and mid-year population estimates⁷ by sex and MSOA for 2015 and for ages 50–89. To approximate period life expectancy at age 65 by income percentile, we first aggregated MSOAs into household income percentiles and then constructed sex-specific life tables by income percentile using a Gompertz-type generalized additive model linking log mortality rates to age and income percentile.⁸ Figures 2a and b show the estimated relationship between income and period life expectancy at age 65. In Figure 2a nominal lifetime income values correspond to the sum of the gender-specific annual incomes between age 20 and age 64, which were approximated using the distribution of income by age and gender for the 2015 financial year as reported by the United Kingdom's HM Revenue and Customs department.⁹

**Figure 2a: E&W period life expectancy in 2015 at age 65
(by individual income percentile)**



⁵ <https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/smallareaincomeestimatesformiddlelayersuperoutputareaseotlandandwales>

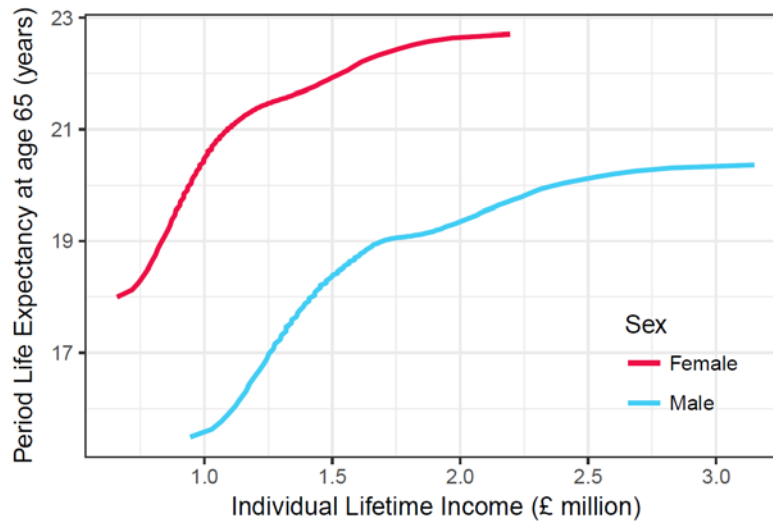
⁶ <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/006416lowersuperoutputarealsoadeathregistrations2015>

⁷ <https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/lowersuperoutputareamidyearpopulationestimates>

⁸ Similar to the US case, mortality rates beyond age 89 were extrapolated using a variant of the method of Coale and Kisker (1990) under the assumption that mortality rates at ages 110 are equal to 0.7.

⁹ <https://www.gov.uk/government/statistics/distribution-of-median-and-mean-income-and-tax-by-age-range-and-gender-2010-to-2011#history>

**Figure 2b: E&W period life expectancy in 2015 at age 65
(by nominal individual Income)**



Source: Office of National Statistics and own estimations.

In comparing the results for E&W and the US it is important to bear in mind that:

- Income "percentiles" for E&W refer to percentiles of average income in local areas and not to percentiles of individual incomes. As individuals in an area will have additional heterogeneity, the actual distribution of individuals' incomes is likely to be more spread, as seen in the US data, for instance.
- Income in E&W is associated with individual income while for the US it is associated with household income. This explains the greater disparity in income by gender observed in E&W as compared to the US.
- The income axis for E&W is much more compressed than for the US, even when considering household versus individual income, and £ versus \$ units.

2.2 Heterogeneity in Longevity as Tax/Subsidy Mechanism: Concept and Estimates

The redistributive effect of heterogeneity in longevity can be easily assessed by translating the outcomes on benefit levels into a tax/subsidy mechanism (Ayuso, Bravo, and Holzmann 2017a). The approach is similar to translating differences in money-worth ratios below and above 1 into tax or subsidy rates.

The general framework is based on an individual contributing tc of her contribution base y^k between age x_0 and retirement age x_r to an NDC pension scheme. The superscript k represents her lifetime income characteristics. These contributions earn a rate of return i and

yield an accumulated capital equal to $AK^k(tc)$ at retirement:

$$AK^k(tc) = tc \cdot \sum_{j=0}^{x_r-x_0-1} y_{x_0+j}^k (1+g)^j (1+i)^{x_r-x_0-j} = tc \cdot Y_{x_r}^k, \quad (1)$$

where g is the rate of increase of the contribution base.

Upon retirement, the notional capital is transformed to an initial pension $P_{x_r}^k$ by dividing the accumulated capital $AK^k(tc)$ by an annuity factor a^k equal to the life expectancy of the cohort when the pre-charged indexation coincides with the discount rate.¹⁰ The annuity factor can be individualized or can be based on the average life table of the cohort. In the latter case, we specify that the superscript k is equal to a . The annuity factor depends on the probability of surviving to age $x_r + j$ after retirement, denoted as ${}_j p_{x_r}^k$:

$$a^k = LE^k = \sum_{j=0}^{\omega-x_r-1} {}_j p_{x_r}^k, \quad (2)$$

where ω is the last possible surviving age.

The difference in mortality becomes more explicit whenever the pension wealth, or pension liability $PW_{x_r}^{c,k}$, is calculated. Indeed, the pension wealth depends on the observed mortality for an individual with characteristics k , even when the pension is based on an average annuity:

$$PW_{x_r}^{c,k} = P_{x_r}^c LE^k = AK^k(tc) \frac{LE^k}{LE^c}. \quad (3)$$

The pension wealth formulae presented above put forward two key concepts when dealing with heterogeneity. The first superscript c indicates the annuity factor used to calculate the pension at retirement. In practice, this is commonly based on the average life table of the population, despite observed differences in mortality.¹¹ The second superscript k indicates that the individual experiences a distinct mortality that depends on lifetime income, education, and other socioeconomic characteristics. It follows from the expression that the pension wealth at retirement equals the accumulated notional capital if the pension is based on the individual's life expectancy.

Following this framework, we can calculate the implicit tax or subsidy rate t^k for the individual with lifetime income characteristics k as:

¹⁰ We could generalize the expression of the annuity to consider indexation rates that differ from the discount rate. However, we choose to abstract from this to obtain intuitive and tractable results. The authors acknowledge that a general annuity could be a tool to deal with mortality heterogeneity as well.

¹¹ As the distribution of the differences is not symmetric, the choice of the average matters. Typically, the arithmetic average is selected whereas the median would be the better choice.

$$t^k = \frac{\text{Pension wealth}}{\text{Accumulated notional capital at retirement}} - 1 = \frac{PW_{x_r}^{c,k}}{AK^k(tc)} - 1. \quad (4)$$

A positive value of t^k represents a subsidy, since the liability in the system exceeds the accumulated contributions paid. This indicates that the individual will receive on average t^k percent more than she has contributed. On the other hand, a negative t^k represents a tax, since the realized liability is lower than the liability in the NDC books.

To clarify the distributionary effects we present the current design of a typical NDC (and for this matter, also FDC) pension scheme. The pension at retirement is calculated with the average life table, whereas the pensioner will have a different mortality experience on average according to her lifetime income characteristics k . In this case, the tax (subsidy) t^k , which can be positive or negative, is represented as follows:

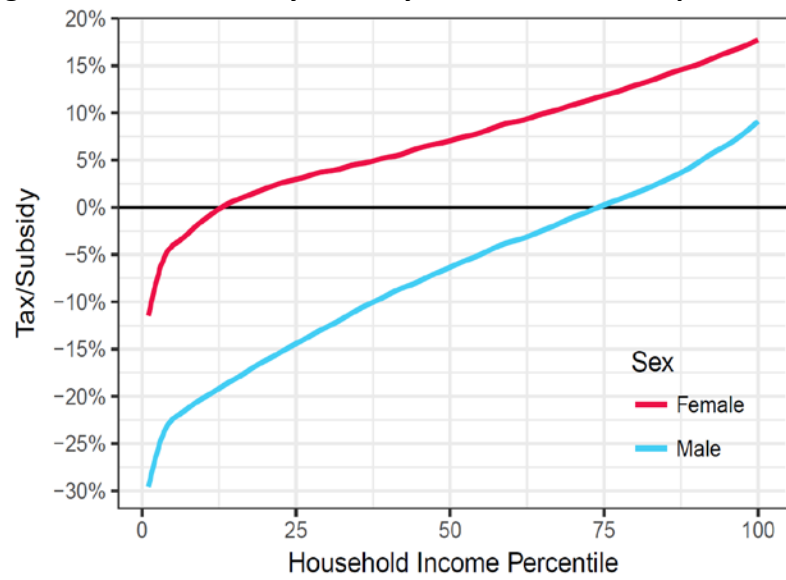
$$t^k = \frac{PW_{x_r}^{a,k}}{AK^k(tc)} - 1 = \frac{\frac{AK^k(tc)}{LE^a} LE^k}{AK^k(tc)} - 1 = \frac{LE^k}{LE^a} - 1 \quad (5)$$

The individual receives a subsidy if $LE^k > LE^a$; that is, if she belongs to a category that lives on average longer than the total population. This typically corresponds to individuals with higher lifetime income. However, those who belong to a category that lives shorter than the total population on average will bear an implicit tax due to the difference in life expectancy.

Ayuso, Bravo, and Holzmann (2017a, 2017b) offer for a number of advanced countries a number of point estimates of tax and subsidy rates that typically reflect the tertiles or quintiles of the income distribution. Using the data of Figures 1 and 2, we estimate and present in Figures 3 and 4 the whole distribution across all percentiles for the US and E&W, respectively. The results lead to the following observations.

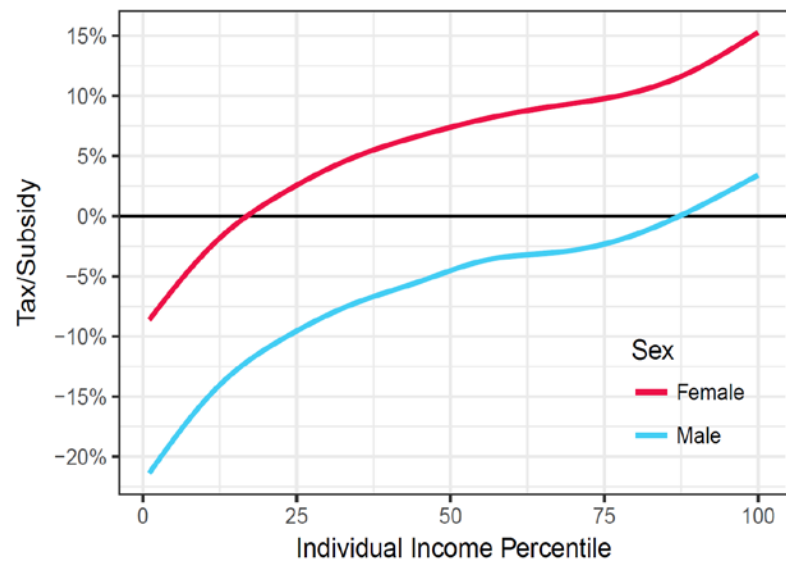
- Given the known higher average life expectancy of women when applying a common average annuity factor – as is the case in social security schemes – all women above the 12th income percentile in the US (16th percentile in E&W) receive a subsidy, while all men below the 73th income percentile in the US (86th percentile in E&W) pay a tax.
- The tax rate of men can be as high as 30 percent for the lowest percentile in the US (below 20 percent in E&W), and the subsidy rate of women can reach as high as 18 percent in the US (and 15 percent in E&W).
- Both men and women in the lowest 10 percent of income in both countries are particularly hit by a high tax rate of heterogeneity that is likely to affect their decisions regarding labor market formality and supply.

Figure 3: US tax/subsidy rates by household income percentile



Source: Chetty et al. 2016, and own calculation..

Figure 4: E&W tax/subsidy rates by individual income percentile



Source: Office of National Statistics and own estimations.

2.3 Implications for Scheme Design and Pension Reform

A relevant and rising scope of heterogeneity in longevity – particularly linking higher life expectancy at retirement with higher accumulations at retirement – has major implications for scheme design and pension reform. This applies specifically to the reform movement in recent decades from defined benefit (DB) to (funded or unfunded) defined contribution (DC) schemes to establish a closer contribution–benefit link and to address population aging by increasing the retirement age(s) in line with increasing life expectancy. If relevant heterogeneity in longevity is left unaddressed in the design and implementation of DC schemes, their underlying design and reform rationale may be called into question. This section thus focuses on three main concerns with NDC schemes; the arguments apply roughly for FDC schemes as well.¹²

First, the beauty of NDC schemes is their simplicity and claimed fairness: What you paid in you get out, and what you get out you paid in, but no more. Any redistributive considerations are transparent, with financing from the outside that happens at the time the commitment is made, not when it is disbursed. This contrasts with NDB schemes, where some redistribution is part of the design but most of it is implicit, creating a tax/subsidy wedge often of unknown size and with unknown effects on distribution, financing, and scheme participation. With sizable heterogeneity among the insured and thus sizable tax/subsidy effects for contributors, the advantages of NDC schemes are lessened and the rationale for an NDC reform reduced.

Second, NDC schemes promise a linear intertemporal budget constraint in which the choice of retirement age depends only on the linear resource constraint and individual preferences for consumption and leisure. Minimum and standard retirement ages, in principle, lose their relevance in an NDC scheme, except for dealing with some behavioral restrictions by individuals in their decision making. As life expectancy at retirement continuously increases, individuals will receive a lower benefit at any given retirement age, which is expected to incentivize them to postpone retirement to smooth their lifetime consumption. This is the case when life expectancy is assumed to be homogenous. However, if individuals realize that the initial benefit is calculated by applying an average cohort life expectancy, even though they have a better assessment of their own longevity, their retirement decision risks being different. Both the poor and the rich have an incentive to retire as soon as possible – i.e., shortly after the minimum retirement age fixed by all NDC countries – as the poor cannot expect to live so long, and the rich can maximize their subsidy.

Last, a critical rationale for NDC schemes' reform is the transparency of their redistributive processes, as alluded to above. With stark heterogeneity, the envisaged distributive neutrality under NDC does not hold and redistributive interventions such as matching contributions or guaranteed income top-ups may be miscalculated. This calls for a clear understanding of the magnitude of heterogeneity and the design alternatives to address it, and a full understanding of how external redistributive interventions will affect individuals with life expectancies that

¹² For a broader discussion of heterogeneity in longevity and pension systems and reform, see Whitehouse and Zaidi (2008); for a discussion of the implications for funded pensions, see OECD (2016); and for suggestions how to address heterogeneity in longevity in the German point system, see Breyer and Hupfeld (2009).

deviate from the applied common average.

3 A Formal Framework to Present Alternative NDC Designs

This section presents five alternatives to the design of the pension paid at retirement, either by modifying the annuity rate or the contribution rate. The government can intervene either at retirement or during accumulation. We analyze three designs that deliver a tax or subsidy of zero when life expectancy is known with certainty. However, in practice, individual-specific improvements and aggregate mortality risk raise the need to perform approximations, as presented in Designs 3, 4, and 5.

Design 1 considers individualized annuities. Design 2 individualizes the contribution rate during the accumulation phase instead of paying individualized annuities. As an approximation, Design 3 splits the contribution rate to accrue both a social and individualized pension. The contribution split suggested in Design 3 works very well only as long as the relationship between life expectancy and lifetime income is broadly linear (in percentile or log income) across the whole income strata, so Designs 4 and 5 address heterogeneity when this is not the case. Design 4 deals with the upper tail of the established longevity–income link and explores the extent to which caps on contribution account allocation but not on payment can address deviations for the highest income group. Design 5 explores the extent to which individualized contribution rates that build on the two-tier design structure are needed to address deviations for the lowest income group.

Design alternative 1: Individualized annuities

The most effective way to reduce the distortionary effects of heterogenous mortality – as defined in equation (4) and (5) – is to pay pensions that depend on the individualized mortality experience instead of using the average mortality rate. If everyone pays the contribution rate tc , the tax or subsidy is reduced to zero:

$$t^k = \frac{\frac{AK^k(tc)}{LE^k} LE^k}{AK^k(tc)} - 1 = 0 \quad (6)$$

Design alternative 2: Individual contribution rates – Versions a and b

An individual approach during the accumulation stage can be achieved in two ways. The first one considers that everyone pays the same rate tc whereas the contribution allocated into the individual notional account is adjusted by differences in life expectancy. A second approach consists of allocating the average notional contribution rate while collecting an individualized contribution rate tc^k that is adjusted for heterogeneity. Both approaches lead to a zero tax/subsidy component but to different allocations/benefit levels at equal retirement age that may lead to different retirement incentives.

In version **2a**, participants pay $tc \cdot y^k$ but are credited $tc \cdot y^k \frac{LE^a}{LE^k}$ to ensure actuarial fairness. The accumulated capital then becomes $AK^k(tc) = tc \frac{LE^a}{LE^k} Y_{x_r}^k$. Indeed, individuals who live longer than average are credited a lower amount than they have contributed to correct for the additional years during retirement. This adjustment also increases the replacement rate for those with a lower life expectancy, facilitating their early withdrawal from the labor force. Upon retirement, the pension is calculated based on the average life table. In this case, the realized liability corresponds to the one present in the books and the tax or subsidy becomes zero:

$$t^k = \frac{\frac{tc \cdot \frac{LE^a}{LE^k} Y_{x_r}^k}{LE^a} LE^k}{tc \cdot Y_{x_r}^k} - 1 = 0. \quad (7)$$

Alternatively, in version **2b**, participants pay the individual contribution rate $tc^k = tc \cdot \frac{LE^k}{LE^a}$, which is related to their life expectancy. If they live longer (shorter) than average they pay more (less) into the pension system. However, they are credited an amount corresponding to the average contribution rate tc . Their accumulated capital at retirement therefore coincides with the expression (1) presented earlier and the replacement rate is equal across the different categories. If the pension is calculated with the average life table, the tax or subsidy becomes zero:

$$t^k = \frac{\frac{tc \cdot Y_{x_r}^k}{LE^a} LE^k}{tc \cdot \frac{LE^k}{LE^a} Y_{x_r}^k} - 1 = 0. \quad (8)$$

Design alternative 3: Two-tier contribution schemes with flat and individualized contribution rates – Versions a and b

This alternative works at the accumulation stage and assumes that pensions paid during retirement are based on the average annuity. To reduce the distortions, individuals pay a total contribution rate tc equal to the one in Design 1. However, the contribution rate is further split between a social contribution sc and an individual contribution nc . The social contribution accrues rights on the median salary, whereas the individual contribution accrues pension rights on the individualized contribution base. The accumulated capital at retirement is then given as follows:

$$\begin{aligned} AK^k(sc, nc) &= \sum_{j=0}^{x_r - x_0 - 1} (sc \cdot y_{x_0+j}^a + nc \cdot y_{x_0+j}^k) \cdot (1+g)^j (1+i)^{x_r - x_0 - j} \\ &= sc \cdot Y_{x_r}^a + nc \cdot Y_{x_r}^k \end{aligned} \quad (9)$$

The two-tier allocation can be rewritten to highlight the redistribution as follows:

$$sc \cdot y_{x_0+j}^a + nc \cdot y_{x_0+j}^k = tc \cdot y_{x_0+j}^k + sc \cdot (y_{x_0+j}^a - y_{x_0+j}^k),$$

An individual earning less than $y_{x_0+j}^a$ receives an additional pension right equal to $sc \cdot (y_{x_0+j}^a - y_{x_0+j}^k)$, whereas someone earning more than the reference level sees her accrued rights decrease by $sc \cdot (y_{x_0+j}^a - y_{x_0+j}^k)$. The split between the social and individual contributions needs to be made at a cohort level to jointly reduce the distortions due to the differences in life expectancy. A way to achieve this goal is to minimize on a cohort basis the squared difference between the pension $P_{x_r}^k(tc)$ from Design 1 based on the unique contribution rate tc and an individualized annuity, denoted as P_1^k for an individual k , and the pension $P_{x_r}^a(sc, nc)$ based on the split contribution rate and the average annuity, denoted as P_2^k for simplicity (Design version a):

$$\min \sum_{k \in I} (P_1^k - P_2^k)^2 = \min \sum_{k \in I} \left(tc \cdot \frac{Y_{x_r}^k}{LE^k} - sc \cdot \frac{Y_{x_r}^a}{LE^a} - (tc - sc) \frac{Y_{x_r}^k}{LE^a} \right)^2 \quad (10)$$

It can be shown that the optimal social contribution sc^* is then equal to:

$$sc^* = tc \cdot \frac{\sum_{k \in I} \frac{Y_{x_r}^k}{LE^k} (LE^k - LE^a) (Y_{x_r}^k - Y_{x_r}^a)}{\sum_{k \in I} (Y_{x_r}^k - Y_{x_r}^a)^2} \quad (11)$$

In this case the tax rate (4) is:

$$\begin{aligned} t^k &= \frac{\frac{AK^k(sc, nc)}{LE^a} LE^k}{AK^k(tc)} - 1 = \frac{sc \cdot Y_{x_r}^a + nc \cdot Y_{x_r}^k}{(sc + nc) \cdot Y_{x_r}^k} \frac{LE^k}{LE^a} - 1 \\ &= \left(1 + \frac{sc}{tc} \left(\frac{Y_{x_r}^a}{Y_{x_r}^k} - 1 \right) \right) \frac{LE^k}{LE^a} - 1 \end{aligned} \quad (12)$$

If $Y_{x_r}^k > Y_{x_r}^a$ and $LE^k > LE^a$, then it is unclear whether a tax or subsidy arises, since the first part of equation (12) would be less than 1 and the life expectancy ratio would be greater than 1.

Alternatively, in version **3b**, we minimize the difference in replacement rates instead, yielding:

$$\min \sum_{k \in I} \left(\frac{P_1^k}{y_{x_r-1}^k} - \frac{P_2^k}{y_{x_r-1}^k} \right)^2 \quad (13)$$

The optimal social contribution sc^* is then equal to:

$$sc^* = tc \cdot \frac{\sum_{k \in I} \frac{Y_{x_r}^k}{LE^k} (LE^k - LE^a) \left(\frac{Y_{x_r}^k - Y_{x_r}^a}{(Y_{x_r-1}^k)^2} \right)}{\sum_{k \in I} \left(\frac{Y_{x_r}^k - Y_{x_r}^a}{Y_{x_r-1}^k} \right)^2} \quad (14)$$

In this case the expression of the tax rate (4) coincides with the one presented in equation (12). However, the value of the tax or subsidy may not coincide since the split stemming from the last minimization between the social contribution and individual contribution may not be the same.

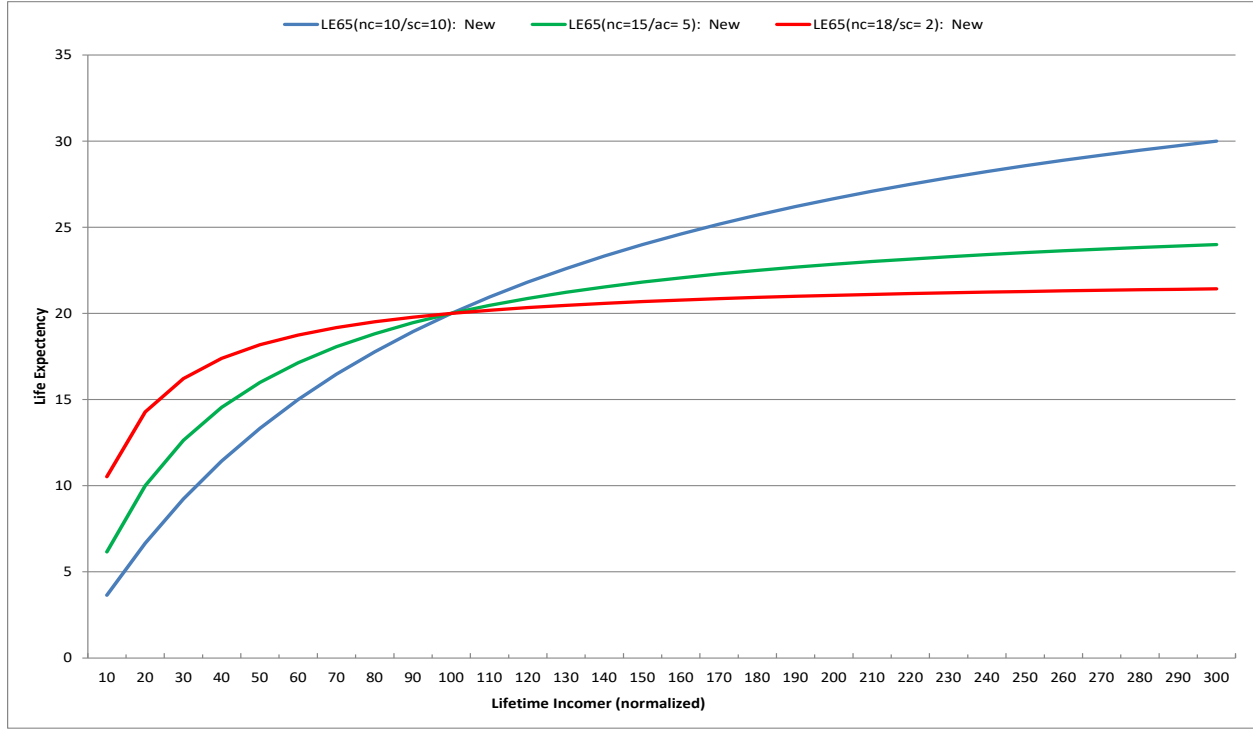
A tax or subsidy rate of zero can be achieved by either individualizing the annuity or the contribution rate. However, as an approximation, implementing a two-tier contribution scheme can help reduce the distributionary effects of current typical NDCs. If the contribution rate tc is split into a social contribution sc accruing rights on the median salary, and an individual contribution nc accruing rights on the individual salary, then the tax or subsidy rate could be reduced. Setting the tax rate to zero derives a link between individual life expectancy as a function of average life expectancy and the relationship between individual and median lifetime income. The closer the empirical link to this functional relationship, the lower the tax/subsidy would be.

$$LE^k = LE^a \left(\frac{tc \cdot Y^k}{tc \cdot Y^a + nc(Y^k - Y^a)} \right) \quad (15)$$

Figure 5 presents the implied relationship between life expectancy and lifetime income for three pairs of individual and social contribution rates. The higher the social contribution rate relative to the individual rate, the more Design 2 is able to compensate for the higher heterogeneity of longevity that is linked to lifetime income inequality. The concave curvature of this relationship is consistent with empirical observations (discussed in Section 2).¹³

¹³ In Ayuso, Bravo, and Holzmann (2017b) a linear relationship between individual life expectancy and lifetime income position is explored. It is derived by equating the tax/subsidy rate under current design for heterogeneous life expectancy with the subsidy/tax rate of a two-tier approach under homogeneous life expectancy.

Figure 5: Actuarial fairness under heterogeneous life expectancy in two-tier contribution scheme for alternative contribution rate splits



Source: Authors, based on equation (15).

Design alternative 4: Two-tier contribution scheme (Design alternative 2a) with caps on the contributions

This alternative seeks to complement Design 2a with the two-tier contribution system when the relationship between lifetime income and life expectancy is not concave in the upper tail (as highlighted with US data in Figure 1). As before, the total contribution rate is split into a social contribution sc and an individual contribution nc . However, the individual and social contribution base is capped for accumulation purposes. In this case, the accumulated capital at retirement $CAK^k(sc, nc)$ is:

$$CAK^k(sc, nc) = \sum_{j=0}^{x_r-x_0-1} \left(sc \cdot y_{x_0+j}^a + nc \cdot (y_{x_0+j}^k + (Cap - y_{x_0+j}^k)1_{y^k > Cap}) \right) \cdot (1+g)^j (1+i)^{x_r-x_0-j} = sc \cdot Y_{x_r}^a + nc \cdot CY_{x_r}^k. \quad (16)$$

This expression indicates that accumulated capital at retirement consists of the following two parts: the social contribution applied to the average wage, plus the individual contribution rate applied to the individual wage. However, if the individual earns more than the cap, the contribution allocated to the individual account remains constant at the cap level.

In this case, the tax is given as follows:

$$t^k = \frac{\frac{AK^k(sc, nc)}{LE^a} LE^k}{AK^k(tc)} - 1 = \frac{sc \cdot Y_{x_r}^a + nc \cdot CY_{x_r}^k}{(sc + nc) \cdot Y_{x_r}^k} \frac{LE^k}{LE^a} - 1 \quad (17)$$

The cap varies substantially across countries, ranging from median income (thus covering fully only 50 percent of the insured) to a multiple of the average income (thus covering fully 90 or even 95 percent of the population). The scope of coverage below the ceiling often has historical reasons and is co-determined by the role of supplementary pensions for those above the ceiling. Historically, the cap was not taking account of heterogeneity. However, differences in longevity could inform the selection of the ceiling. If those in the upper 5th or 10th percentile deviate upwards in their life expectancy from an empirically established concave pattern for the large majority of the population, then such a ceiling selection under a Design 4 approach would make sense. How well the Design 4 approach is able to correct for such a deviation needs to be investigated in a country setting.

Design alternative 5: Two-tier contribution scheme (Design alternative 3a) with individualized contribution rates

We next blend Design alternative 3a – i.e., a two-tier contribution rate structure – with Design alternative 2 – i.e., an individualized contribution rate allocation. The individual pays an individual contribution rate tc^k but credits the total contribution rate under a social and individual contribution rate split. Upon retirement, the accumulated capital is transformed to a pension with the average life table. The tax is then given as follows:

$$t^k = \frac{sc \cdot Y_{x_r}^a + nc \cdot Y_{x_r}^k}{(sc + nc) \cdot \alpha \cdot Y_{x_r}^k} \frac{LE^k}{LE^a} - 1$$

It follows from the expression above that α needs to be chosen as:

$$\alpha = \frac{sc \cdot Y_{x_r}^a + nc \cdot Y_{x_r}^k}{(sc + nc) \cdot Y_{x_r}^k} \frac{LE^k}{LE^a} \quad (18)$$

to achieve an actuarially fair pension scheme ($t^k = 0$). Consistent with Design 3, it is not straightforward to determine whether the correction to the contribution rate α will be higher or lower than 1, increasing or decreasing the contribution rate accordingly.

A second and more operationally oriented Design alternative 5b seeks to complement Design 3 for the lowest tail of the income distribution. As Figures 1 and 2 for the US and E&W suggest, the lowest 5 percent of the population's estimated life expectancy seems below even that of the established concave curvature of a two-tier approach. If this were the case for the most marginalized insured, compensation through the social contribution share would not be sufficient to establish broadly actuarial neutrality.

4 Empirical Application and Exploration

This section offers some empirical evidence regarding the effectiveness of the key policy options in reducing the effects of heterogeneity. To compare among policy options, we apply a total tax measure that aggregates the individual tax/subsidy rates across the available percentile data of lifetime income and the related period life expectancies at age 65. For this aggregate average measure, we use the absolute values so that tax and subsidy rates are added up; both are an indication of fairness distortions. This Total Absolute Tax Subsidy Indicator (TATSI), defined as the sum of the absolute values of the individual tax and subsidy rates, is fully comparable across all policy options.

We explore two policy options: individualized annuities and the two-tier contribution scheme. Both appear empirically, politically, and operationally feasible. We leave out the individual contribution Design 2 that would be applied during the accumulation phase, as it raises a number of operational and policy issues. For data and space reasons, neither do we delve into the alternatives that deal with the tails of the distribution. When presenting Designs 1 and 3, we use the current situation, denoted Design alternative 0, as the benchmark.

Design alternative 0: Almost status quo

We start with the results of TATSI for Design alternative 0 – our benchmark – and explore two rate estimations: the rate for pooled life expectancy and the rate when life expectancies between men and women are separated; i.e., the individual tax/subsidy rate is calculated based on gender-specific average life expectancy. Table 1 summarizes the results.¹⁴

Table 1: Design alternative 0 – Aggregate tax/subsidy rate indicators for E&W and the US

	E&W				US			
	Joint pool		Separate pools		Joint pool		Separate pools	
	Women	Men	Women	Men	Women	Men	Women	Men
Nominal tax/subsidy rate	6.02%	-6.02%	0%	0%	7.05%	-7.05%	0%	0%
Absolute tax/subsidy rate	7.34%	6.48%	4.28%	5.00%	8.02%	9.16%	4.73%	8.31%
	Total		Total		Total		Total	
Nominal tax/subsidy rate	0%		0%		0%		0%	
TATSI	6.91%		4.64%		8.59%		6.52%	

Source: Author's calculations. TATSI = Total Absolute Tax/Subsidy Indicator.

¹⁴ For the following estimations, we use for the observed data the smoothed mortality data for both E&W and the US. Using the raw data would not make any difference in scope and conclusions.

Table 1 indicates for E&W a TATSI of 6.91 percent for the traditional joint pool of both genders. The gender-specific tax/subsidy rates differ slightly between women and men, being higher for men as the difference between the highest tax and subsidy is larger. Applying separate pools for gender reduces the gender-specific absolute rate significantly for women, but little for men. The TATSI value for E&W is reduced to 4.64 percent, or by one-third. The results for the US are similar in the direction of change but with altogether higher values. The joint pool value of 8.59 percent is reduced through separate pooling to 6.52 percent, or almost by one-quarter. These results suggest that risk pool separation may be a critical ingredient for the reduction of TATSI in countries, but it is not sufficient.

Design alternative 1: Individualized annuities

In many existing annuity markets, annuity rates are derived using age and gender as the only rating factors, ignoring any socioeconomic variation in mortality. However, in more advanced markets such as the United Kingdom, the importance of considering differential mortality for the valuation of pension liabilities and the pricing of annuities has been recognized. Lifestyle and socioeconomic mortality profiling is common in the UK bulk annuity market and is increasingly being used in the pricing of individual annuity products and in the valuation of pension portfolio liabilities (Richards 2008; Ridsdale and Gallop 2010; Gatzert and Klotzki 2016). Variables used by insurers and pension providers in estimating an individual's mortality include postcode, salary, pension, smoking status, and occupation. As illustrated in Madrigal et al. (2011) and Richards, Kaufhold, and Rosenbusch (2013), such variables are typically considered using generalized linear models or survival models applied to large and detailed datasets of historical individual mortality. Life expectancy per lifetime income over the years would allow to better estimate impacts of alternative pension designs over generations. We hypothesize that public institutions running NDC schemes at a national level would be able to produce such data: estimates for lifetime income along the income distribution – e.g., for each percentile – and the corresponding estimated period or cohort life expectancy, and differentiated by gender. Estimations by the National Academies of Sciences, Engineering, and Medicine in the US in 2015 offer a possible approach in addition to the datasets for the US and E&W applied above. The estimation of individual life expectancy for individuals within a percentile cohort may be enhanced by other socioeconomic characteristics such as education and geography, etc., if considerations of magnitudes and relevance suggest so.

Here we follow a much simpler approach. We want to measure by how much TATSI is reduced compared to the starting position – Design alternative 0 – if we estimate the life expectancy of a percentile (compared to the untreated estimate) through a simple life expectancy–lifetime income relationship. To this end, we explore three specifications:

Linear
$$LE_k = a + b \cdot Y_k$$

Quadratic
$$LE_k = a + b \cdot Y_k + c \cdot Y_k^2$$

Power
$$LE_k = a + b \cdot \log Y_k$$

Figures 6a-c and Figures 7a-c illustrate the observed and approximated link between life expectancy and lifetime income – for joint and separated gender pools – for E&W and the US, respectively.

As the figures clearly show, the individualization of annuities works broadly well when the gender pools are disaggregated. The simple quadratic specification, and at times the power specification, does a reasonable job of approximation.

Figures 6a-c: E&W **Figures 7a-c: US**
Observed and approximated life expectancies – individualized annuities

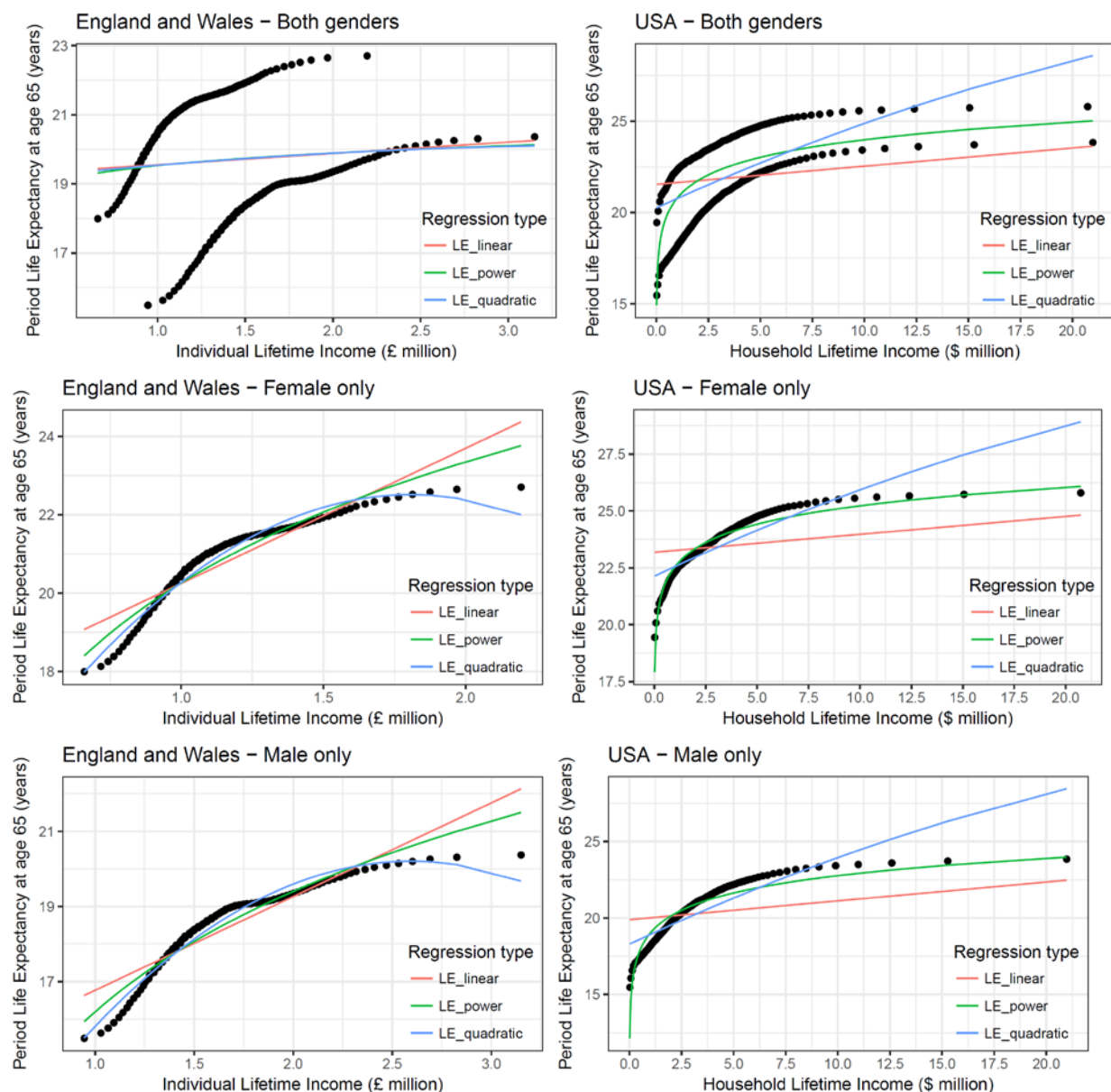


Table 2 presents the data behind Figures 6 and 7. The mere approximation of individual life expectancy in the joint pool brings a moderate reduction in TATSI for the US and a slight deterioration for E&W. However, when the pools are separated by gender, even simple individualization of annuities leads to a reduction in TATSI by more than half in the US compared to the gender-separated value in Table 1 – from 6.52 to 2.90; the reduction is even stronger in E&W, from 4.64 to 0.95 (i.e., by about 80 percent).

Table 2: Individualized annuities - aggregate tax/subsidy rate indicators

	E&W				US			
	Joint pool		Separate pool		Joint pool		Separate pool	
	Women	Men	Women	Men	Women	Men	Women	Men
Nominal tax/subsidy rate	6.45%	-6.45%	0.00%	0.00%	7.28%	-7.26%	-0.01%	-0.05%
Absolute tax/subsidy rate	7.47%	6.52%	0.88%	1.02%	7.36%	7.33%	2.06%	3.75%
	Total		Total		Total		Total	
Nominal tax/subsidy rate	0%		0%		0%		0%	
TATSI	6.99%		0.95%		7.34%		2.90%	
	Linear		Quadratic		Power		Quadratic	

Source: Author's calculation. TATSI = Total Absolute Tax/Subsidy Indicator.

Design alternative 3: A two-tier contribution scheme

The other promising approach to reduce the distortionary effects of heterogeneity in longevity in an NDC scheme is to introduce the two-tier contribution approach presented in Section 3. Carving out a social contribution rate sc under a total contribution rate of 20 percent (our assumed rate for the exploratory calculations) and linking this rate to the average, not the individual income/contribution base, offers this correction. It creates a tax for those with income above the average that counteracts the subsidy they receive from living longer than the average, and vice versa for those below the average.

Table 3 presents the estimated social contribution rate for alternative policy specifications as per equation (11). Essentially one can calculate separate social contribution rates under common life expectancies, common social contribution rates under gender-separated life expectancies, and separate social contribution rates under gender-separated life expectancies. The results indicate that the magnitude of the social contribution rate is moderate. It remains

well under 4 percentage points out of 20 percent (i.e., a share of lower than one-fifth).

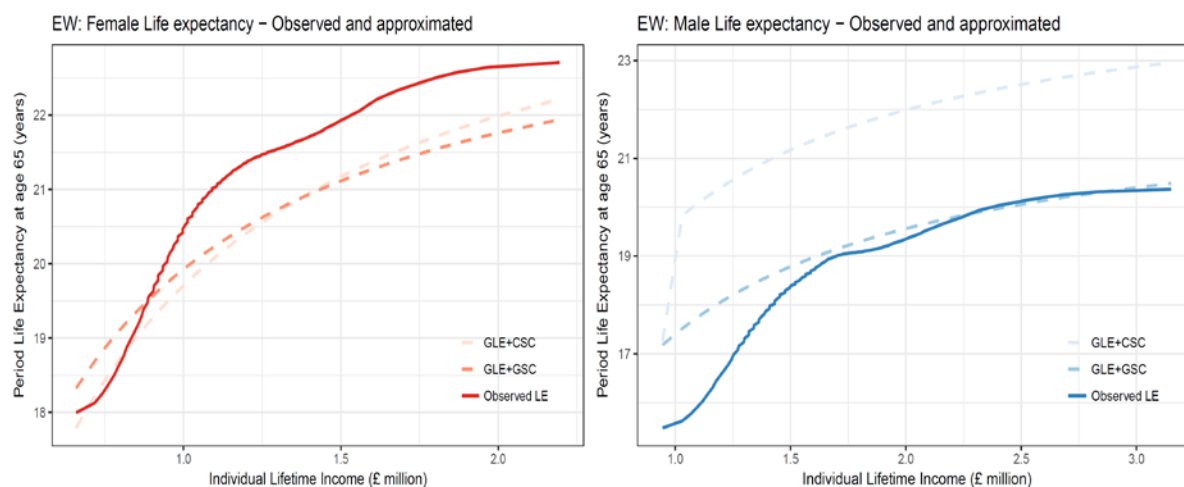
Table 3: Social contribution rates for alternative specifications

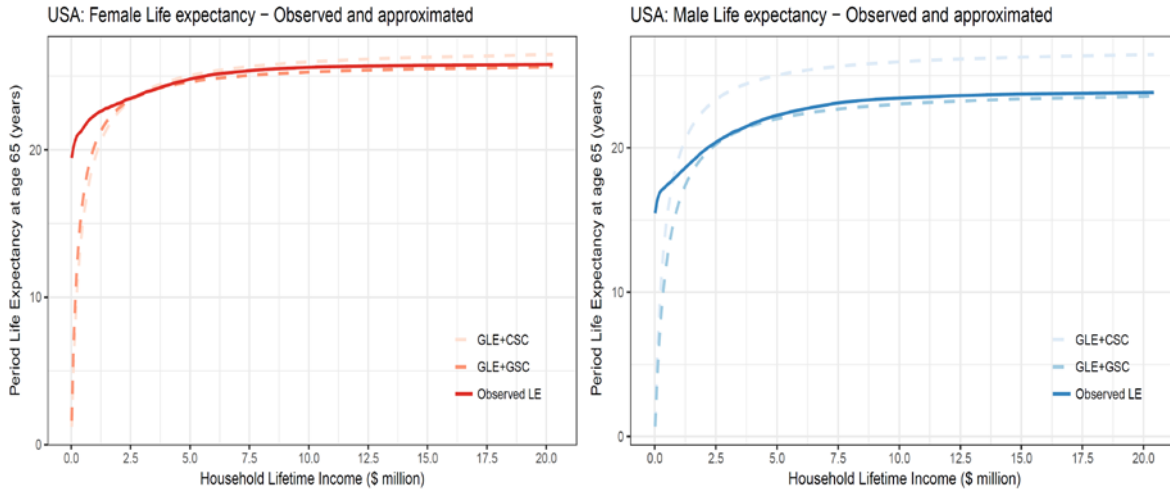
E&W			US		
Common life expectancy					
sc population	0.58%		sc population	2.45%	
sc women	1.15%		sc women	3.16%	
sc men	0.34%		sc men	1.70%	
Separate gender life expectancies					
sc population	3.21%		sc population	2.56%	
sc women	2.58%		sc women	1.89%	
sc men	3.42%		sc men	3.09%	

Note: sc = social contribution.

Figures 8a-d present again the observed life expectancies for both E&W and the US, but this time with the approximated life expectancies implied by the two-tier scheme (as per equation (15)) and based on the estimated social contribution rates from Table 3. The approximations presented differ by the choice of the social contribution rate (common across both genders (CSC) or gender-separated (GSC)); in all cases, life expectancies are separated by gender. The casual observation suggests that the approach works broadly well, particularly when the genders are separated.

Figures 8a-d: Observed and approximated life expectancies – two-tier contribution scheme





Figures 9a-b map the approximated life expectancies into the tax/subsidy space to see how well and for which percentiles the two-tier scheme succeeds in keeping TATSI close to the zero tax line. Here, we are looking not for proximity in the lines, but how close the TATSI approximations are to the zero tax rate axis.

Figures 9 a-b: Observed and approximated Total Absolute Tax/Subsidy Indicator (TATSI)

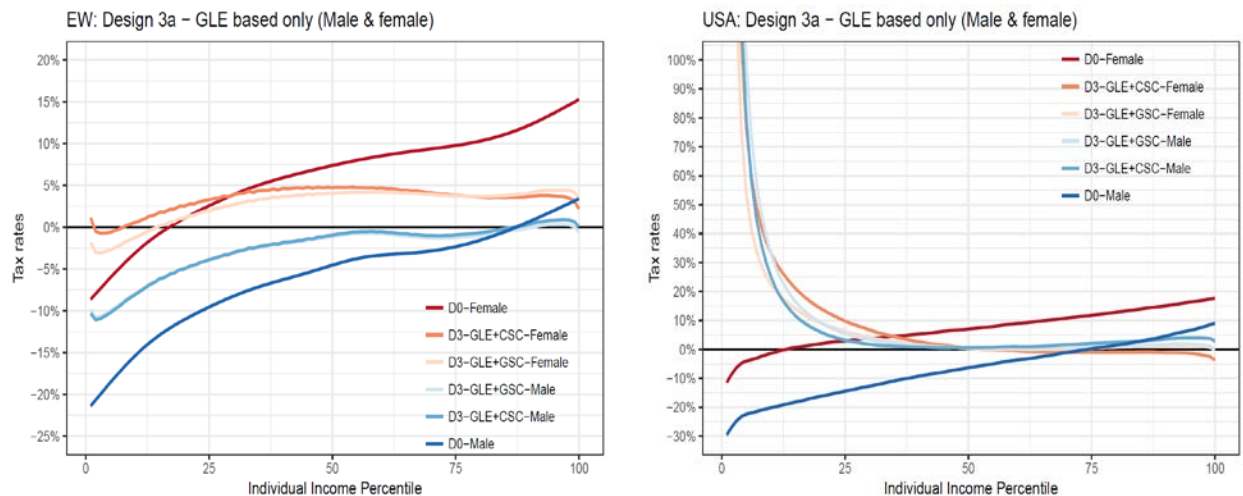


Table 4 translates the data for Figure 9 into the TATSI values.

Table 4: Two-tier contribution scheme - aggregate tax/subsidy rate indicators

	E&W				US			
	Separate pool		Separate pool		Separate pool		Separate pool	
	Women	Men	Women	Men	Women	Men	Women	Men
Nominal tax/subsidy rate	3.41%	-2.52%	2.74%	-2.68%	27%	30%	20%	37%
Absolute tax/subsidy rate	3.47%	2.67%	3.23%	2.72%	28%	30%	20%	37%
	Total		Total		Total		Total	
Nominal tax/subsidy rate	0.89%		0.05%		57.49%		56.64%	
TATSI	3.07%		2.98%		29.21%		28.32%	
	Pooled sc		Separate sc		Pooled sc		Separate sc	

Source: Authors' calculations. TATSI = Total Absolute Tax/Subsidy Indicator; sc = social contribution.

The results in Table 4 signal that for E&W a two-tier scheme does a reasonable job in reducing TATSI values under Design alternative 0 – the starting value of Table 1. The TATSI value is more than half compared to that of joint pooling but only one-third compared to that of separate gender pooling. Hence, most of the reduction results from separate pooling. The lifetime income approximations via the two-tier scheme add some, but altogether moderate, further reductions. This design alternative for E&W, however, is dominated by the option of gender-separated individualized annuities. Interestingly, little difference arises between pooled or separately calculated social contribution rates.

The latter result also applies for the US, but TATSI increases to a multiple of the starting value and is well above that seen in the individualized annuity design alternative. Furthermore, in the US, the result for TATSI differs little between the joint and the separate gender pool. This outcome is due to the high subsidies the lowest 20th percentile receives under a two-tier contribution option – both men and women. The lowest income decile in the US has both low income and low contribution density, which translates into these very high subsidy rates. For the other 80 percent of the insured, the tax/subsidy rate under a two-tier scheme is around +/-1 percent or less and thus almost perfect. Hence, for the US a two-tier NDC scheme could address three policy objectives with one instrument: a close contribution–benefit link for the vast majority of the population; elimination of the distortionary effects of heterogeneity in longevity for this population; and a major old-age income support for those in the lowest income percentiles.

The US actually already has a very progressive benefit structure that limits the replacement rate for individuals at the ceiling to some 36 percent, while offering a replacement rate of over 100 percent for the lowest income percentiles. It will be left to another paper to explore the

difference between both approaches in detail.

5 Summary and Next Steps

Increasing international evidence shows that heterogeneity in longevity is high and relevant for policy outcomes. It is hypothesized that this negatively impacts pension schemes' performance, including recently reformed schemes that moved toward DC schemes to improve the contribution–benefit link. Heterogeneity in longevity risks undoing this link and, given the transparency of DC schemes on the link between initial benefit and average life expectancy at retirement, makes the resulting distortions even more relevant.

This paper moves the analytical and policy discussion forward, using two country datasets that are able to present the whole distribution space on the link between life expectancy and measures of lifetime income. These data for the US (provided by Chetty et al. 2016) and E&W (self-constructed from national data) allow analysis of the tails of the income distribution, where the distortions are highest. Building on the tax/subsidy conceptualization of heterogeneity in longevity, the distribution data over all lifetime income percentiles allow construction of aggregate measures of distortions. TATSI (Total Absolute Tax and Subsidy Indicator) can be applied to alternative policy designs to compare their capability to reduce the distortions. Alternative designs are modeled under a common framework and include: individualized annuities; individualized contribution rates/account allocations; a two-tier contribution structure with socialized and individual rate structure; and two supplementary approaches under the two-tier approach to deal with the distribution tails, and the distortions above a ceiling and below a floor.

This paper uses these new data to explore the two most promising design alternatives: individualized annuities and the two-tier contribution approach. Compared to the status quo, both design alternatives succeed in reducing tax distortions. This happens through the approximation of the observed individual life expectancy with estimated individual life expectancy, and perhaps more importantly by disaggregating life expectancy by gender when the calculations are made. Applying the two-tier contribution scheme in the US may improve efficiency and the redistributive outcome over the current progressive tax-benefit approach.

De-pooling life expectancy by gender reduces distortions/improves efficiency, but further increases the gap between men's and women's pension levels due to a not-yet-eliminated gender wage gap and continued reduced income prospects for women with children. This begs the question whether gender pooling is the best instrument to address the gender pension gap or whether it would be better addressed through: (i) direct labor market policies to reduce the wage gap; (ii) social policies to compensate the contribution loss due to childbearing and rearing; and/or (iii) an annual contribution-splitting between partners to balance labor market outcomes. A direct approach may allow appropriate pension design to efficiently separate allocative and redistributive considerations.

The next steps for this research are to:

- Access or construct similar life expectancy/lifetime income data for other countries and improve on lifetime estimates, and the link to other heterogeneity characteristics, particularly education. This would improve the estimates and make them even more policy relevant.
- Explore empirically the full set of policy alternatives developed and presented, and develop new ones. In particular, deeper investigation of the tails of the distribution is required.
- Empirically compare results across countries to better understand what may simply be a statistical issue or artifact, or whether issues exist that require policy interventions beyond heterogeneity.

References

- Ayuso, Mercedes, Jose Bravo, and Robert Holzmann. 2017a. "On the Heterogeneity in Longevity among Socioeconomic Groups: Scope, Trends, and Implications for Earnings-Related Pension Schemes." *Global Journal of Human Social Sciences-Economics* 17(1): 33-58.
- _____. 2017b. "Addressing Longevity Heterogeneity in Pension Scheme Design." *Journal of Finance and Economics* 6(1): 1-24.
- Breyer, Friedrich, and Stefan Hupfeld. 2009. "Fairness of Public Pensions and Old-Age Poverty." *FinanzArchiv/Public Finance Analysis* 65(3): 358-380.
- Chetty, Raj, Michael Stepner, Sarah Abraham, Shelby Lin, Benjamin Scuderi, Nicholas Turner, Augustin Bergeron, and David Cutler. 2016. "The Association Between Income and Life Expectancy in the United States, 2001-2014." *Clinical Review & Education Special*, 315(16), 1750–1766. <https://doi.org/10.1001/jama.2016.4226>
- Coale, Ansley J., and Ellen Kisker. 1990. "Defects in Data on Old Age Mortality in the United States: New Procedures for Calculating Approximately Accurate Mortality Schedules and Life Tables at the Highest Ages." *Asian and Pacific Population Forum* 4: 1–31.
- Gatzert, Nadine, and Udo Klotzki. 2016. "Enhanced Annuities: Drivers of and Barriers to Supply and Demand." *The Geneva Papers on Risk and Insurance - Issues and Practice* 41(1): 53–77. <https://doi.org/10.1057/gpp.2015.21>
- Holzmann, Robert. 2017. "The ABCs of Notional Defined Contribution (NDC) Schemes." IZA Policy Discussion Paper No. 130, August. Published in *International Social Security Review* 70(3), October 2017.
- Madrigal, Ana M., Fiona E. Matthews, Deven Patel, Andrew Gaches, and Steven Baxter. 2011. "What Longevity Predictors Should Be Allowed For When Valuing Pension Scheme Liabilities." *British Actuarial Journal* 16(1): 1–38.

- National Academies of Sciences, Engineering, and Medicine. 2015. "The Growing Gap in Life Expectancy by Income: Implications for Federal Programs and Policy Responses." Committee on the Long-Run Macroeconomic Effects of the Aging U.S. Population-Phase II. Committee on Population, Division of Behavioral and Social Sciences and Education. Board on Mathematical Sciences and Their Applications, Division on Engineering and Physical Sciences. Washington, DC: The National Academies Press.
- OECD. 2016. "Fragmentation of Retirement Markets Due to Differences in Life Expectancy." In OECD Business and Finance Outlook 2016, Chapter 6. OECD Publishing, Paris: 177-205.
- Richards, Stephen. J. 2008. "Applying Survival Models to Pensioner Mortality Data." *British Actuarial Journal* 14(2): 257–303.
- Richards, Stephen. Kai J. Kaufhold, and S. Rosenbusch. 2013. "Creating Portfolio-Specific Mortality Tables: A Case Study." *European Actuarial Journal*.
<https://doi.org/10.1007/s13385-013-0076-6>
- Ridsdale, Brian, and Adrian Gallop. 2010. "Mortality by Cause of Death and by Socio-Economic and Demographic Stratification 2010." *International Congress of Actuaries 2010*.
- Whitehouse, Edward, and Ashgar Zaidi. 2008. "Socio-Economic Differences in Mortality: Implications for Pensions Policy." OECD Social, Employment and Migration Working Papers, No. 71. OECD Publishing. <http://dx.doi.org/10.1787/231747416062>